Appendix I – GPRA06 Solar Energy Technologies Program Documentation

1. Introduction

This appendix provides detailed information on the assumptions and methods employed to estimate the benefits of EERE's Solar Energy Technologies Program. The benefits analysis for the Solar Program utilized both NEMS and MARKAL as the analytical tools for estimating the Program's benefits. As will be discussed below, a number of assumptions and structural modifications to the models were made in order to represent the suite of solar technologies funded by the program as accurately as possible (Photovoltaics, Concentrating Solar Power and Solar Water Heating). Many of the assumptions used in the FY06 analysis are the same as or similar to those employed in the FY05 analysis; however, two key changes are important to highlight up-front. First, the AEO2004 analysis used a new set of reference case assumptions with respect to photovoltaic technology cost reductions. The new sets of reference case assumptions are very similar to the Solar Program's targets for PV. This shift in assumptions necessitated developing a new approach for estimating the baseline (i.e., no program) input assumptions for PV. Second, the FY06 analysis included CSP technology benefits – CSP benefits were not included in the FY05 analysis.

The body of this appendix contains two sections. The first discusses the assumptions used to construct the GPRA06 Solar Program baseline scenario. The second discusses the modifications that were made to this baseline to construct the GPRA06 solar program scenario.

2. GPRA06 Solar Program Baseline Assumptions

Several changes from the AEO2004 Reference Case were incorporated into the GPRA06 Baseline. These changes include the following:

Revising projected PV cost. The AEO2004 reference case assumptions for PV technology costs were based on a recent report published by Navigant Consulting (2003). As shown in **Figure 1**, the cost projections in the new EIA reference case are very close to the Solar Program's targets. Because of this shift in EIA's reference case assumptions, a new set of baseline assumptions for PV technology needed to be developed. In constructing the GPRA06 baseline, the following approach was used. Between 2005 and 2015, the costs of PV are assumed to decline more slowly in the GPRA06 baseline, leading to a five-year lag between the GPRA06 baseline and the program's goals by 2015. Beyond 2015, the GPRA baseline and program numbers are assumed to continue to diverge. This approach incorporates a relatively conservative estimate of the Solar Program's impact on the cost of PV technology and captures the notion of technological lock-in (Cowan and Kline 1996).

Increasing the average commercial building system size from 10kW to 100kW. A sample of data from 14 PV systems installed by PowerLight Corporation, between July 1999 and March 2003, reveals that the average commercial system installed by PowerLight during this period was 381kW (**Table 1**).

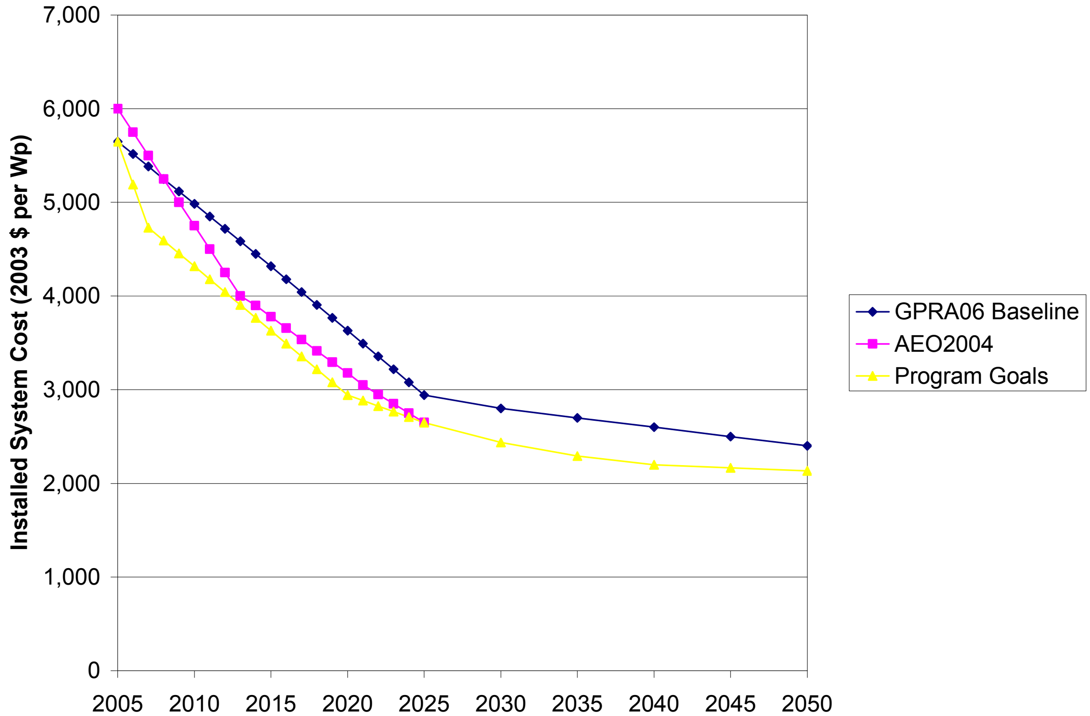

Figure 1. Projected PV Commercial System Costs

Table 1. Commercial System Size and Surface-Area Requirements

PowerLight System Installation Location	Date Completed	System Peak Capacity (kW)	PV Surface Area (sq. ft.)	W/sq.ft.
Santa Rita Jail - Alameda County, California	Apr-02	1,180	130,680	9.0
Cypress Semiconductor - San Jose, California	Jul-02	335	26,100	12.8
Fala Direct Marketing - Farmingdale, New York	Nov-02	1,010	102,700	9.8
Fetzer Vineyards, Hopland, California	Jul-99	41	3,750	10.9
Franchise Tax Board, Sacramento, California	Aug-02	470	50,000	9.4
Greenpoint Manufacturing - Brooklyn, New York	Mar-03	115	11,500	10.0
Mauna Lani Resort – Kohala Coast, Hawaii	Jan-02	528	43,330	12.2
Naval Base Coronado, California	Sep-02	924	81,470	11.3
Neutrogena Corporation - Los Angeles, California	Aug-01	229	30,154	7.6
Parker Ranch – Kameula, Hawaii	Jan-01	209	20,000	10.5
PSGA/Ortho-McNeil Facility - Pennsylvania	Apr-02	75	17,500	4.3
U.S. Coast Guard – Boston, Massachusetts	Sep-99	37	3,800	9.7
U.S. Postal Service - Marina del Rey, California	Nov-01	127	15,000	8.5
Yosemite National Park - Yosemite, California	Oct-01	47	4,500	10.4
Total		**5,327**	**540,484**	
Average		**381**	**38,606**	**10**

Source: PowerLight Case Study data sheets, Downloaded from www.powerlight.com, 5/21/03.
Note: Some of the locations shown in this table have multiple installations. In these cases, the total installed capacity is shown above and the most recent installation date is shown in the date-completed column.

The average space required for these systems was 0.1 sq. ft/W., based on a U.S. average commercial building size in 2000 of 14,500 square feet (AEO2003), and assuming a ratio of usable roof space to floor space of 0.7. This ratio of usable roof space to floor space was based on the "architecturally suitable area" in an International Energy Agency (IEA) report, Table 2, examining the potential for integrated photovoltaics in buildings (IEA 2001). Using this approximation, the average commercial building could easily accommodate a 100 kW PV system, i.e., a 0.7*14,500 sq. ft. = 10,100 sq. ft. PV array. Thus, setting the average system size at 100kW is a conservative assumption based on industry trends, as well as the available roof space on a large share (50+%) of the commercial building stock. This is a very conservative assumption based on the expectations that the efficiency of PV cells will increase; the space requirements for a PV system will decrease; and, as system costs decline, facades and other spaces (such as parking lots) also could be utilized for PV systems.

Increasing the maximum share of commercial buildings with solar access from 30% to 55%. Similar to the preceding ratio of usable roof space to floor space, the share of roof space suitable for PV installations was based on the recently published IEA report on integrated photovoltaics in buildings (IEA 2001). This report indicates that a reasonable estimate for the share of roof space suitable for PV installations is 55%. This estimate includes shading and other factors that would limit the use of roof space for PV systems (IEA 2001).

Increasing the average residential building system size from 2kW to 4kW. A couple of years ago, a typical residential rooftop PV system was a 2kW system—this is most likely the source for EIA's 2kW system size in the *AEO2004* reference case. However, residential rooftop systems being installed in Japan, Europe, and the United States have been growing larger. For example, the average Japanese rooftop system size in 2002 was 3.7 kW (Ikki 2003) and the average rooftop system size in California in 2004 was 3.6 kW[1]. The average home in the United States has 1,700 square feet of floor space (this is expected to increase in the future). Using data from EIA's residential energy-consumption survey (EIA 1999, Table HC1-2a) one can estimate a floor- to roof-space ratio of 0.7 (based on distribution of one-story, two-story, and three-story single-family homes). This is a conservative estimate—most homes have pitched roofs, which would increase the total available roof space (yet may make a significant portion of the roof oriented away from the sun). If a typical system requires 10 sq. ft./W (as above), then a 4kW system would require roughly 400 square feet of roof space, which is well below the average available space allowing for multiple floors and pitched roofs. Thus, roof space is not a constraint for installing residential rooftop PV systems in the 4kW range. Because the efficiency of PV cells is likely to improve, a trend toward larger systems on rooftops is likely to continue. Thus, based on available roof space and what is happening in the marketplace, setting the average system size at 4kW is a conservative assumption.

Increasing the maximum share of residential buildings with solar access from 30% to 60%. A maximum share of 60% for residential buildings with solar access was used. This estimate

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[1] This estimate was based on data from the California Energy Commission's Emerging Renewables Program, downloaded on 1/27/05 from www.energy.ca.gov/renewables/emerging_renewables.html. Data on small PV systems (i.e., with a system size under 10kW) were extracted from the full dataset, indicating that during 2004 a total of 15.9 MW of PV was installed in 4,372 small PV systems in California with an average system size of 3.6kW.

accounts for the fact that some homes will not be suitable for PV systems due to shading, building orientation, roof construction, or other factors. This value was calculated from a combination of single-family homes (70%) and multifamily homes (30%), using a 75%–25% split between single-family and multifamily homes (EIA 2003, Table A4). Thus, the average maximum share was set at 0.7*0.75 + 0.3*0.25 = 0.6.

Including a declining PV buy-down program in California. This assumed that the California renewable energy credit program that provided a PV credit of $4,000/kW in 2003 will continue to be available, but will decline by $400/kW per year. This credit was included for the entire Pacific region. Given that a number of other local credits were not included in the GPRA baseline, applying the California state-level credit to the whole Pacific region is likely to be a reasonable approximation.

Modifying the adoption rate of distributed generation technologies. The modification to the adoption rate was based on information provided by the DER program (**Figure 2**). This applies to PV as well as gas-fired CHP technologies.

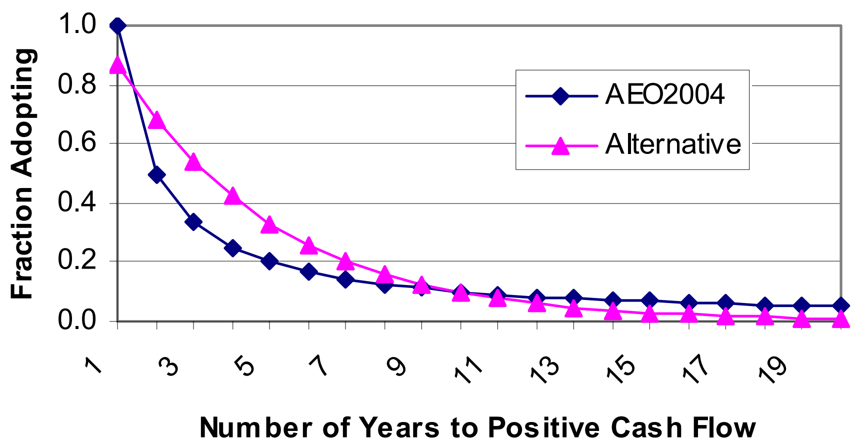

Figure 2. Commercial-Sector DG Adoption Rates

These changes lead to increased adoption of PV systems in the baseline. However, the *AEO2004* assumptions about PV installations through the Million Solar Roofs program were removed, so that there would not be double-counting when these were introduced in the GPRA Program Case.

One additional NEMS-GPRA06 model modification was made in the residential module. Solar water heaters were added as a technology option for new homes, and the algorithm governing water heater replacements was modified so that solar water heaters could compete in a larger market.

3. GPRA06 Solar Program Scenario Assumptions

Three key sets of assumptions were modified to generate the GPRA06 Solar Program scenario.

Green power additions. Green power additions by region, from Princeton Energy Resources International (PERI), were added back into the Solar Program scenario (**Table 2**). These projections take into account the Baseline assumptions of noneconomic capacity additions. This capacity is added in NEMS-GPRA06 as exogenous additions in residential and commercial buildings. Note that the CSP green power builds were very small (<70MW), so they were not include in the GPRA06 analysis.

Table 2. Incremental Green Power PV Capacity Additions (MW)

Incremental Green Power PV Capacity Additions (MW)					
	2006-2010	2011-2015	2016-2020	2021-2025	Total
ECAR	80	183	140	40	443
ERCT	73	167	127	36	404
MAAC	70	159	122	35	385
MAIN	21	47	36	10	113
MAPP	5	12	9	3	29
NY	15	35	27	8	84
NE	20	47	36	10	113
FL	94	214	164	47	518
STV	282	641	491	140	1,554
SPP	76	173	132	38	418
NWPP	13	31	23	7	74
RA	24	54	42	12	132
CNV	0	0	0	0	0
Total	773	1,761	1,348	385	4,267

Technology Characteristics. More aggressive technology targets were used for the range of solar technologies: concentrating solar power (CSP), central PV systems, distributed PV systems, and solar water heating systems. These technology characteristics were based on the Solar Program's most recent Multi-Year Technical Plan (EERE 2004), and the solar baseline scenario assumptions contained in Margolis and Wood (2004).

In order to define a consistent set of long-term targets going out to 2050, a multi-lab, multi-technology team was assembled in 2003. This team produced technology cost projections for use in NEMS that are consistent with the Solar Program's Multi-Year Technical Plan through 2025 and extended the Solar Program's targets to 2050 (for details, see Margolis and Woods 2004). Thus the targets shown in **Tables 3, 4 and 5** are consistent with the Multi-Year Technical Plan through the 2020-2025 timeframe. Beyond 2025, the targets are increasingly uncertain and are likely to be revised as the Solar Program continues to analyze the long-term prospects for PV technology cost reductions. Note that, on an annual basis, costs are assumed to decline linearly between the years shown in the tables below.

While the technology assumptions for commercial rooftop PV systems are shown above in **Figure 1**, detailed data for PV systems in the three markets modeled is provided in **Table 3**. Although the costs shown below are for specific years, the costs decline annually between the years shown. Note that in both the GPRA baseline and program scenarios, the AEO2004 Reference Case assumptions for solar insolation and capacity factors were used.

Table 3. PV Systems

	Central Generation		Residential Buildings		Commercial Buildings	
Year	Installed Price (2001$/kW)	O$M (2001$/kW)	Installed Price (2000$/kW)	O$M (2000$/kW)	Installed Price (2000$/kW)	O$M (2000$/kW)
2003	5,300	60	9,450	160	6,250	160
2007	3,600	40	6,250	40	4,500	40
2020	2,000	10	2,800	10	2,800	10
2025	1,800	9	2,520	9	2,520	9
2050	1,450	7	2,029	7	2,029	7

In NEMS, two solar water heaters are represented that have different efficiencies or electric backup requirements. In MARKAL, only one type of solar water heater is represented (shown in **Table 4** at the typical efficiency system).

Table 4. Residential Solar Water Heat

		Best (High efficiency)		Minimum (Typical efficiency)	
First Year	Last Year	Efficiency	Total Installed Cost($01)	Efficiency	Total Installed Cost($01)
1997	2004	2.5	3050	2.0	2800
2005	2009	2.6	2650	2.1	2500
2010	2019	2.7	1650	2.2	1500
2020	2025	3.0	1450	2.5	1300
2030	n.a	n.a	n.a	2.8	1162
2040	n.a.	n.a	n.a	3.0	1098

Notes: n.a. = not applicable. Change in data after 2030 reflects data structure in MARKAL.

The data for CSP technology shown in **Table 5** are for California. The CSP costs are up to 13% higher in other regions with less solar insolation to account for greater capacity and storage requirements. The annual capacity factors by 2020 range from 49% in MAPP (the Upper Midwest) to 74% in the Southwest. The capacity factors by time period were computed by Sandia analysts to optimize the timing of solar output for each region within the bounds of the storage potential. Note that the AEO2004 Reference Case assumptions include lower-cost CSP systems, but with significantly less storage and therefore lower electrical output.

The future cost assumptions for CSP technology in the Solar Program scenario are based on a funding level consistent with the FY06 budget request for FY06 and a funding level commensurate with those outlined in the Draft CSP Technology Transition Plan for years beyond FY06 (DOE 2004).

Table 5. Concentrating Solar Power

Year	Installed Price ($/kW)	O$M (mills/kWh)	Capacity Factor
2003	4,953	14.7	53%
2010	3,510	7.8	65%
2020	2,462	4.0	72%
2025	2,199	3.6	72%
2030	1,993	3.2	72%
2035	1,879	3.1	72%
2040	1,826	3.0	72%
2050	1,797	2.9	72%

4. Sources

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